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The overall objective of this project was to design the microstructure and to test the fracture toughness and creep-rupture properties of metal-matrix composites constructed from NiAl and aluminum oxide. The goal has been to obtain a composite that not only has excellent high temperature creep properties, but also has good fracture toughness at room temperature. Principal microstructural variables have been (i) the crystallographic texture in the metallic phase, (ii) the bonding of the metal-ceramic interface, and (iii) the degree of interpenetration (percolation) of the phases, particularly the metal phase. The latter is greatly affected by the volume fraction of the ceramic phase, the metal ligament size constrained between the ceramic particles, and the grain size of the intermetallic phase.

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FINAL TECHNICAL REPORT

ASSERT-92: The Design of Metallic Composites Made form Nickel Aluminide

Cornell University **F49620-93-1-0308**

S. Leigh Phoenix (from Rishi Raj)

FQ8671-9301131 **01 Jun 93 - 31 May 97 (FINAL)**

Graduate Student: Maurice Granger (Materials Science)

Grades: Excellent, Passed Q-exam

Graduate Student: David Shia (Theoretical and Applied Mechanics)

Grades: Excellent, Q-exam to be taken May, 1998

Research Performed:

The overall objective of this project was to design the microstructure and to test the fracture toughness and creep-rupture properties of metal-matrix composites constructed from NiAl and aluminum oxide. The goal has been to obtain a composite that not only has excellent high temperature creep properties, but also has good fracture toughness at room temperature. Principal microstructural variables have been (i) the crystallographic texture in the metallic phase, (ii) the bonding of the metal-ceramic interface, and (iii) the degree of interpenetration (percolation) of the phases, particularly the metal phase. The latter is greatly affected by the volume fraction of the ceramic phase, the metal ligament size constrained between the ceramic particles, and the grain size of the intermetallic phase.

The first graduate student on the project was Maurice Granger, a PhD student in Materials Science. Over a two year period (up to August 1996, no suitable student was found the first year of the project) he developed a "dead weight creep tester" that was designed to measure stress-rupture lifetime in tension of relatively brittle materials at temperatures up to 1,500oC. A carefully designed loading train was fabricated entirely from ceramics to sustain the high testing temperatures. This turned out to be a major effort. Results from the stress-rupture experiments are reported in Figure 1. Three sets of data, one from NiAl-65 v/o Al2O3, another from NiAl-15 v/o Al2O3, and the third from single phase NiAl polycrystals (also prepared by Granger) are shown. All experiments were carried out at the applied tensile stress of 31 MPa, and the testing temperatures ranged from 1,327oC for the highest volume fraction to 1,000oC for the single phase NiAl polycrystals. The stress rupture life ranged from 200 seconds to 106 seconds (approximately 10 days).

As a first round of tests these results (lifetimes) were promising. Upon normalizing for the lower density, these already had a better performance index in comparison to state-of-the-art superalloys. Apart from generating more data, however, these results motivated the need for micromechanical analysis of the creep-rupture process, together with computational mechanics techniques to see how diffusional creep mechanisms interact in the microstructure to yield the observed performance. The goal would be to use such modeling to synthesize and design materials with optimal performance.

In September of 1996, PI Rishi Raj left Cornell University to take a position at the University of Colorado, and Prof. S. Leigh Phoenix took over as principal investigator. This was a natural transfer as Prof. Phoenix had been on the PhD Special Committee of Mr. Granger and was familiar with the work. About the same time graduate student Maurice Granger decided to leave the project and graduate student David Shia was appointed to take his place as a Graduate Research Assistant. Over the year Mr Shia performed some analysis to determine micromechanical interactions between the NiAl and Al2O3 that might determine the resulting creep performance and especially the localization leading to creep-rupture. He performed average-based calculations with special interface models to predict tensile stiffness of such systems, with the goal of extending this to creep. He quickly found that the governing interactions are statistical and that local micromechanical interactions between phases, especially those connected to creep in the NiAl, and cavitation at grain boundaries, would need to be captured realistically with new computational techniques. Finite element techniques were not sufficiently efficient, could not perform sufficient replications, and nor could they treat aggregates with enough particles or grains to capture the key effects. Thus he began work to develop influence function techniques based on key unit problems of the process to capture the key interactions. This is the subject of his PhD thesis, which is in the early stages of development. Some progress has been made, building on related work of two other PhD students formerly under the direction of PI Phoenix on other projects in this area. This work is expected to take at least two more years and will be supported on other funds since the current AASERT award has been terminated as of May 31, 1997.